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Nutrient Management in Silvopastoral Systems for Economically and Environmentally Sustainable Cattle Production: A Case Study from Colombia

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1. Introduction

In recent years, livestock production has received negative publicity due to environmental degradation. Critics charge that the expansion of cattle production around the world has destroyed the forest, increased soil erosion, and has contaminated the environment. These negative effects have been caused by poor decisions in the production system. Nevertheless, there are possible solutions. Given ongoing climate change, fears of environmental contamination, and global market competition, silvopastoral systems emerge as a valuable alternative to develop an economic, productive, and environmentally-friendly system for livestock raising in the world. The purpose of this chapter is to give a general description of the silvopastoral systems and to provide a synopsis of the main productive and environmental benefits obtained by using them for dairy and beef cattle production. Most of information in this chapter is inspired by the Colombian experience during the past 20 years.

2. What are silvopastoral systems?

In Colombia and much of Latin America, the traditional cattle production systems have been based on grass monoculture (treeless pastures) as the main food source. According to **Steinfeld et al. (2006),** the development of this kind of cattle production system has led to extensive deforestation, soil degradation, and contamination of water bodies and the environment. In Colombia, the annual deforestation rate of 300.000 ha for expansion of pasturelands has seen this land use more than double from 14.6 to 35.5 million ha between 1960 and 1995, while natural forests and agriculture have declined in area from 94.6 to 72.4 million ha (**Lavh et al., 1998**). This land use transformation has homogenized and simplified the ecosystems and has negatively impacted the quality of the environment and its ecological diversity (**Mahecha, 2002**; **Giraldo et al. 2011**). The problem is exacerbated by the increasing degradation of soils and grasslands in areas used by cattle, which has reached levels of 73.4, 68.5 and 94.1% in the Córdoba, Sucre and Atlantic departments, respectively (**CORPOICA, 2010**). Ironically, this transformation has not made cattle production systems more effective, economically and productively. The traditional cattle production system in

Picture 1. Lucerna cows grazing in a high density silvopastoral system. Picture: Liliana Mahecha, in Hatico Natural Reserve

Colombia exhibits low productivity and competitiveness (**Colombian Ministry of Agriculture and Rural Development, 2005**) expressed as low number of animals per ha (average 1.2), low birth rate (less than 69%) and low weight daily gain (between 350-450 g/d) (**Mahecha et al. 2002**). These parameters have shown only modest productivity increments during the last 10 years, with a few exceptions. It is predicted that the situation will worsen in coming years due to the global climate change. According to the **IPCC (2007),** the air temperature will increase from 2.4 to 6.4º C with an average of 4.0ºC increasing 0.2ºC per decade, which is expected to cause a decline in animal performance (**Nardone et al., 2010**).

Unfortunately, this kind of production system and its negative environmental impacts have raised criticism about livestock raising around the world. However, appropriate production strategies with correct environmental management would help in restoring degraded ecosystems, provide environmental services (**Calle et al., 2002**), and improve productivity (**Mahecha, 2003**). One of the strategies that can be used to reduce the impact of this activity is the implementation of silvopastoral systems (SPS).

SPS are animal production systems that combine fodder plants, such as grasses and leguminous herbs, with shrubs and trees for animal nutrition and complementary uses (**Mahecha, 2002; Murgueitio et al., 2011**). The strategic management of nutrients and the interactions between components of the system has an important impact on the environment, productivity, and society.

3. What types of silvopastoral systems exit?

Trees used in SPS can be from natural vegetation or planted for timber, industrial products, fodder and fruit or specifically for animal production (providing shadow, fodder, seeds, wood) (**Mahecha, 2002**). Therefore, there are several types of SPS such as protein and energy banks (cut and carry systems), live fences, wind barriers, and low and high density silvopastures (**Picture 2**, **Mahecha, 2002**). The advantages of the high density silvopastures are the best known. The selected type depends on the topography, type of soil, and the presence of strategic areas for water, soil or biodiversity conservation. For that reason, it is important to have in mind the use of the different areas of the farm according to needs: protecting from livestock trampling and grazing the fragile areas or areas that are important to conserve the biodiversity or water, grazing in appropriate areas of pastures with low and high density of trees, and using areas to produce fodder (cutting and carrying) where direct access of cattle is not recommended because they would increase erosion, thus direct grazing should be avoided (**Murgueitio and Ibrahim 2001**).

Picture 2. Silvopastoral systems: protein bank (*Cratylia argentea* bank, Candelaria farm, University of Antioquia, high density, low density (*Prosopis juliflora* trees, Hatico Natural Reserve), and wind barriers (Colombia coffee area). Picture: Liliana Mahecha.

4. Main shrubs and trees used in silvopastoral systems

One of the main ongoing research activities of research on going about in SPS is the identification and characterization of different shrubs and trees that can be used as forage for animals, especially incorporating them into the SPS for direct intake by the animals. In Colombia, several species have been evaluated such as: *Leucaena leucocephala*, *Tithonia diversifolia*, *Crescentia cujete*, *Erythrina fusca*, *Gliricidia sepium*, *Guazuma ulmifolia*, *Moringa Oleifera*, *Cratylia argentea*, *Acacia decurrens*, *Sambucus peruviana.* **Table 1** summarizes some nutritional characteristics of these plants for use as animal feed. Besides forage plants, other species have been identified in Colombia to be for wood, shade, and/or nitrogen fixation (**Table 2**). The farmers' decision making about what kind of tree should be incorporated in a SPS is influenced by a combination of factors: soil characteristics, purpose of production, type of grass involved, weather conditions, and other factors (**Mahecha, 2003**). However, one of the main aspects to consider is the relationship between the different components of the system because complex interactions occur between livestock, trees, and pasture in SPS. For example, the key factor of the success of SPS that involves timber trees is to achieve a compromise between the two sources of economic benefit. Grazing is possible when the tree canopy allows light to reach the understory layer, with recommended canopy covers less than 50% (**Pasalodos-Tato, 2009**). Light infiltration to the understory was affected in a silvo-pastoral system with *Eucalyptus tereticornis* and *Panicum maximum* in the San Sebastian reforestation program in Magdalena Department of Colombia when tree height was greater than 10 m using tree density of 3 x 1.5 m (**Mahecha et al. 2007**). In all cases, it is very important to promote nutrient recycling to support plant communities and livestock sustainably.

Species	Crude protein	Ether extract	Neutral detergent fiber	Acid detergent fiber	Calcium	Phosphorous	Source
Acacia decurrens	17.8	3.5	39.2	30.6	0.7	0.3	Chamorro and Rey, 2009
Sambucus peruviana	23.8	5.2	19.4	17.3	9.2	0.9	Chamorro and Rey, 2009
Montanoa cuadrangularis	25.9		48.8	34.6	-	-	Chamorro and Rey, 2009
Tithonia diversifolia	22.6	2.3	35.3	30.4	2.1	0.4	Mahecha and Rosales, 2005
Leucaena leucocephala	26.3			14.1	1.2	0.2	Mahecha et al. (2000)
Guazuma ulmifolia	13-17	-	46.1[1]	29.4[1]	0.9	0.3	Calle and Murgueitio, (2011) [1]Manriquez et al. (2011)
Crescentia cujete (fruit)	12.5	14.8	-	-	0.4	0.4	Calle et al. 2011
Erythrina fusca							
Gliricidia sepium	10.4	-	55.0	41.8	-	-	Lucero (2009)

Table 1. Chemical composition (%) of the forage of some trees used in silvopasture (SPS) in Colombia

5. Impact of the silvopastoral systems on the soil

The incorporation of trees (shrubs and/or trees) in SPS increases soil fertility, improves soil structure, and reduces erosion processes. **Ramirez (1998)** found that the presence of legumes trees in pastures led to an increase in the content of soil nutrients such as nitrogen (N), phosphorus (P), and carbon (C) at depth of 10-30 cm, compared to grass monoculture (**Table 2**). **Rodriguez (1985)** also found higher amounts of organic matter, N and Ca in soil of SPS containing *E.poeppigiana* trees and *P. purpureum* grass compared to monoculture grass. These results have been explained by the increased recycling of nutrients, N_2 fixation, the extensive rooting of trees and greater activity of soil macro and micro fauna given the greater mass of litter and organic residues from diverse plant species and livestock (**Mahecha, 2002**).

Treatment	Soil depth 0-10 cm			10-20 cm			20-30 cm		
	N gkg-1	P ppm	C gkg-1	N gkg-1	P ppm	C gkg-1	N gkg-1	P ppm	C gkg-1
SPS	1.4	29	16.8	1.1	25	14.0	2.2	15	9.2
Grass monoculture	0.8	16	10.0	0.6	16	7.0	1.2	15	4.8

Source: Ramirez (1998)

Table 2. Concentration of total N, P, and C in different soil depths of a silvopastoral system (SPS of *C.plectostachyus* grass + *Leucaena leucocephala* and *P. juliflora* compared to grass monoculture

Nutrient cycling and fixation: the management of grass with trees and/or shrubs recycles nutrients extracted from the soil when vegetation (roots, leaves, fruits) dies and decomposes, from manure of grazing animals and residues from tree pruning (**Sadhegian et al. 1998**). A positive balance was found after one year for N (+16 kg/ha) and P (+1 kg/ha) in silvopastoral systems comprised by native grass and *Leucaena leucocephala* compared to grass monoculture where the balance was negative for N (-15 kg/ha) and P (-6 kg/ha) (**Crespo et al. 1998**). Additionally, most of trees used in SPS are legumes that have the capacity to fix nitrogen from the atmosphere through the association with bacteria living in root nodules. These bacteria can change inert N_2 to biologically useful NH_3, which is then converted to protein in the plant (**Lidemann and Gloves, 2008**). In the SPS of Colombia, legumes provide the main input of nitrogen for pastures. Such systems can substantially reduce inputs of chemical fertilizers and have the added benefit of improving feed quality for grazing animals, especially in the high density SPS. **Ramírez (1997**) found high productivity of forage without using urea fertilizer was achieved by the introduction of shrubs of *Leucaena leucocephala* and trees of *Prosopis juliflora* in the plots (**Table 3**). Other non-legume plants may also be beneficial for soil fertility, such as *Tithonia diversifolia* (**Mahecha and Rosales, 2005**). It is unclear whether the ability to restore degraded soils by *T. diversifolia* is because of the association with mycorrhizal fungi, which are efficient at capturing soil phosphorus or because of the exudation of organic acids by roots that allows for efficient assimilation of phosphorus and other nutrients (**Calle and Murgueitio, 2010**).

Treatments	T1	T2	T3
Fresh forage (t/ha/year)	108.4	121.4	81.7
Dry matter (%)	30.9	31.6	28.4
C. plectostachyus (t DM/ha/year)	33.4	38.3	23.2

T1 - *C. plectostachyus* + *L. leucocephala* (10000 plantas/ha), *P. juliflora* (10 trees/ha)
T2 - *C. plectostachyus* + *P. juliflora* (18 trees/ha) + 400 kg urea/ha/year
T3 - *C. plectostachyus* + 800 kg urea/ha/year.

Table 3. Productivity of *C. plectostachyus* associated with *L. leucocephala* and *P. juliflora*

Rooting depth: the wide, deep root systems of trees in SPS increases the available area for nutrient capture and helps maintain nutrient stocks by reducing leaching losses or by taking up nutrients from deeper soil layers (**Beer et al. 2003**).

Higher diversity and activity of micro and macro fauna: the higher content of organic matter in soil and the improvement of the microclimate (moisture and temperature) due to the presence of trees in SPS promotes the biological activity of the macro and micro fauna, resulting in a greater mineralization and availability of soil nutrients. In addition, organic matter is incorporated gradually into the soil by the action of soil fauna. This helps to improve soil stability, due to the production of stable soil aggregates, and water infiltration capacity through pores constructed by the macrofauna, earthworms in particular (**Belsky et al. 1993**). A study carried out in Caqueta, Colombia compared soil fauna in two production systems: native grass and grass plus leguminous trees (SPS); after 3 years, SPS had 59 taxa of macro-invertebrates at family level and a total of 913 individuals per sampling unit while native grass (monoculture) had values of 30 and 305 individuals, respectively (**Gómez and Velasquez, 1992**). In another study carried out in Cuba, it was found 300 individuals / m^2 in soil from SPS compared to 170 individuals / m^2 in soil from treeless improved grass (**Sanchez, 1998**). Similarly, **Velasco et al. (1999)** found higher numbers of endomycorrhizal fungi and earthworms in soil from SPS of *A.mangium* and *Brachiaria humidicola* compared to grass monoculture. In the same way, **Pardo-Locarno (2009)** found higher earthworm populations in soil from high density SPS compared to other land uses at the Hatico Natural Reserve in Colombia (**Figure 1**). Likewise, **Giraldo et al. (2011)** found that the adoption of SPS promotes the recovery of ecological processes regulated by the increase of dung beetles in the Colombian Andes compared to treeless improved pastures. These authors report that changes in the number of dung beetles is considered an important indicator of land-use change and pasture health. The activities of these beetles are linked to a wide variety of ecological processes, including the incorporation of organic matter into the soil and the control of haematophagous flies and gastrointestinal parasites that breed in manure and affect domestic animals and humans. In the same way, **Vallejo et al. (2010)** assessed the effect of a silvopastoral chronosequence in a tropical region of Colombia on soil microbiological and physico/chemical properties, considering three production systems: monoculture grass conventional pasture (CP), native forest (F), and a silvopastoral system (SPS) chronosequence with ages of 3 to 6 (SPS_3), 8 to 10 (SPS_8), or 12 to 15 (SPS_{12}) years. SPS_{12} showed the highest microbial biomass and enzyme activities on a per unit C basis and was consistently and significantly different from CP. Additionally, microbiological to C ratios were significantly affected by SPS establishment age ($P < 0.05$). The low microbiological responses were consistent with high penetration resistance and bulk density of CP, which indicates that the SPS are improving soil quality. This study presented quantitative data that SPS stimulated soil microbial biomass and enzyme activities, which indicates greater potential to carry out biogeochemical process, and that SPS provides a more favorable microbial habitat than CP.

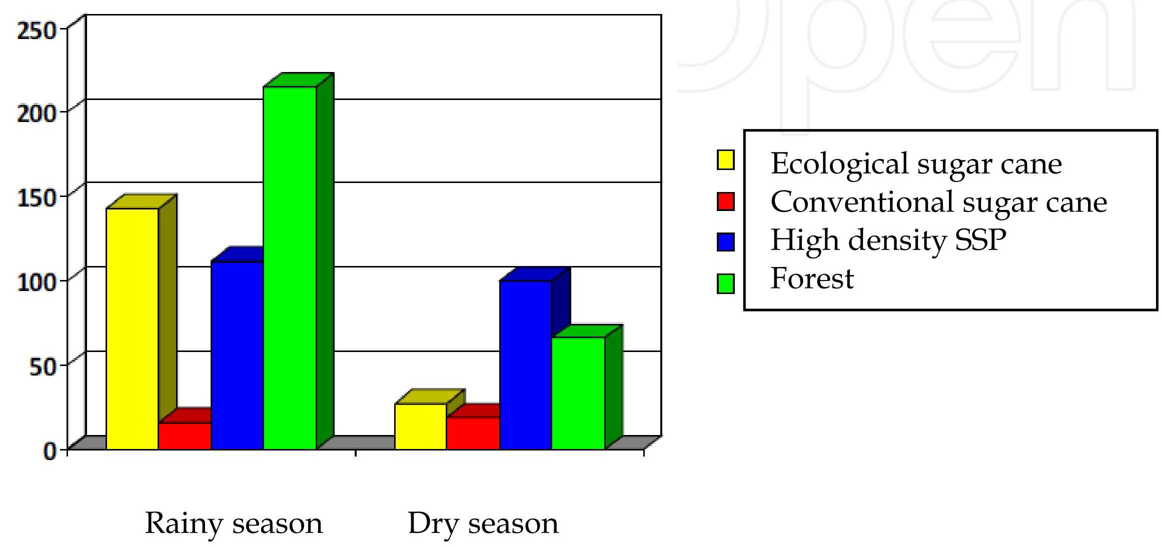


Fig. 1. Density of earthworm per 0.75 m^3 in four land uses in the Hatico Natural Reserve, Colombia. Source: **Pardo-Locarno (2009)**

Erosion control: trees in SPS fulfill protect the soil from the direct effects of sun, wind and water (**Fassbender, 1993**). **Gomez and Velasquez (1999)** showed that the loss of soil in areas without protection of trees is higher than in forest (**Table 4**). The control of erosion by trees is due to several factors: reducing the impact of rain, increasing the infiltration and increasing the stability of the organic matter.

The effect of SPS on the physical characteristic of the soil was evaluated in the "Mainstreaming sustainable cattle ranching project" carried out in Costa Rica. Results showed lower runoff and erosion in SPS compared to treeless improved pastures. Likewise, soil in SPS had higher infiltration rates which improves its ability to retain water, reduce runoff, and contributes to the regulation of water cycle **(Figure 2)** (**Rios, 2006**).

	Slope	Stocking rate	Loss of soil (ton/ha/year)
Forest	32	---	0.61
Grass monoculture	22	1.5	8.23
Bare soil	24	---	20.4

Source: Gómez and Velasquez (1999)

Table 4. Loss of soil per year in Caquetá, Colombia with and without tree coverage

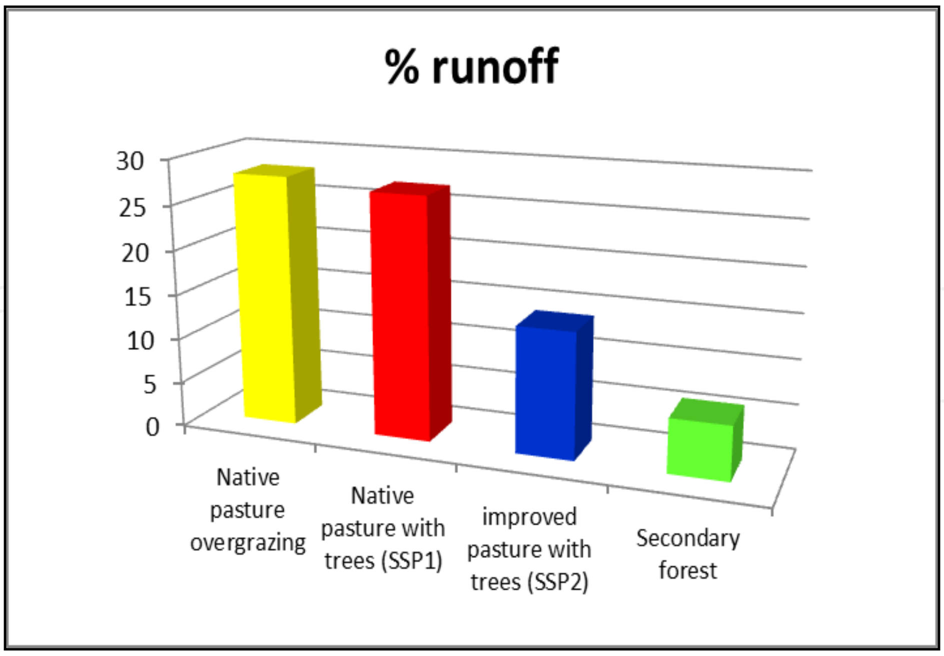


Fig. 2. Average superficial runoff rate for 50 rainfall events in different livestock production systems around the Jabonal river, Costa Rica. Source: **Rios (2006).**

6. Impact of the silvopastoral systems on the environment

The removal of forest for implementation of treeless improved pastures for cattle production impacts negatively the carbon content in the soil due to increase in surface temperature that accelerates the oxidation of organic compounds. The most profound difference is seen when comparing forest to degraded pastures, where carbon stocks are 42 t C/ha in forest and decline to 34.5 t C/ha in pastures (**Ibrahim, 2001**) This decrease in organic carbon content leads to loss soil fertility and increases the emission of greenhouse gases. Reforestation, SPS, and protection of forest in the tropics (for instance, increasing forest cover from 300 to 600 thousand ha) would retain and store between 36 to 71 Pg of C over 50 years (**Ibrahim, 2001**). In a study carried out in Colombia´s Amazon region, the carbon sequestration in pasture and silvopastoral systems under conservation management was evaluated. Results of 5 years of research (2002-2007) show that improved and well-managed pasture and SPS can contribute to the recovery of degraded areas as C-improved systems (**Table 5**).

Land use system	Total C in soil (t/ha per 1m-eq)	%	Total soil in pasture (t/ha)	%	Total C in fine roots (t/ha)	%	Total C in thick roots, trunks, and leaves (t/ha)	table	Total C in system (t/ha)
Native forest	181[a]	61.7	-	-	-	-	112.4	38.3	293.4
B.decumbens + legume	172[b]	98.1	0.9	0.5	2.4	1.4	-	-	175.3
B.humidicola	159[c]	96.6	1.1	0.7	4.5	2.7	-	-	164.6
Degraded pasture	129[d]	97.4	0.9	0.7	2.6	1.9	-	-	132.5

Means with different letters differ statistically (P<0.05), Source: Amezquita et al. (2008)

Table 5. Carbon in soil and biomass of tropical rainforests in Colombia's Amazon region

7. Impact of the silvopastoral systems on the forage availability and quality

The introduction of legumes trees in pastures (SPS) improves the quality of forage of the associated grass compared to forage of treeless improved pastures. It is also possible to increase the total amount of forage for animals, but this depends on factors such as the management of trees, environmental conditions, tree density and species. In a study carried out by **Mahecha et al. (2000)** in the Hatico Natural Reserve located in Valle del Cauca, Colombia, a SPS of *Cynodon plectostachyus, Leucaena leucocephala* and *Prosopis juliflora* showed a forage production of *C.plectostachyus* of 25 t DM/ha/year without fertilization and under the influence of the climate patterns known as El Niño-Southern Oscillation (ENSO). This production was higher than that found by **Ramirez (1998)** in treeless improved pasture of *C.Plectostachyus* (21 t DM / ha / year) on the same farm under no influence of ENSO when fertilizer was applied (400 kg urea / ha / year). In addition, the protein content and in vitro digestibility of grass in the SPS (12% and 64.7%, respectively), with rotational grazing every 42 days, was better than those reported in the literature for treeless improved pasture. It is also important to keep in mind that in the SPS, besides forage production from the grass (25 t/ha/year), cattle also graze on forage from the leaves and thin branches of *Leucaena leucocephala* (4.3 t DM / ha / year) and leguminous pods of *Prosopis trees* (0.4 t DM /ha/ year) that falls to the ground twice a year. Thus, this kind of high density SPS offered a total oc 29.9 t DM /ha / year compared with 21 t MS / ha / year from grass alone in the treeless improved pasture, based on the values reported by **Ramirez (1998).**

8. Impact of the silvopastoral systems on the beef cattle production

Mahecha et al. (2011) evaluated the animal performance and carcass features of two breeds of dual purpose cattle grazing on intensive SPS. The animals were divided in two groups: G1: mostly crossbred genotype F1 * Zebu, G2: animals with F3 * Brahman. Animals were evaluated for 263 d in SPS of *L.leucocephala, C. plectostachyus* and timber trees. The average daily weight gain was 863 and 796 g/animal/d for G1 and G2 respectively. G1 had 60.66 cm^2 of *longissimus dorsi* eye area (AOL) and 6.77 mm of backfat thickness (BT) while G2 had 64.55 cm^2 AOL and 6.44 mm BT, respectively. These results represent the high quality of the forage in the SPS since animals did not receive dietary supplements. In contrast, **Vasquez et al. (2005)** report an average daily weight gain of 578 g/animal/day, AOL between 43-54 cm^2, and BT between 3.0-4.3 mm in different improved systems in treeless pastures.

Although animal performance is positive in SPS, it is necessary to consider that the success depends of the positive relationship between the components of the system. **Mahecha et al. (2007)** evaluated the effect of tree height on the grass availability and quality and on the daily weight gain of young Zebu steers in a SPS of *Eucalyptus tereticornis* and *Panicum maximum* during the dry season in the reforestation program "San Sebastian" in Madalena, Colombia. In addition, the impact of the animals on the tree growth and on soil fertility was estimated. The treatments were: T1: *Eucalyptus tereticornis* + *Panicum maximum*, density 3 x 1.50 m, height of trees 5 m. T2: *Eucalyptus tereticornis* + *Panicum maximum*, density 3 x 1.50 m., height of trees 10 m. Each treatment was accompanied by a plot with similar conditions, but without the presence of animals (T4) to be able to compare tree growth with and without cattle present. These authors demonstrated that animal performance, soil fertility, and tree growth can be positive in a short-term, but could be altered in a long-term because SPS with very high tree density can affect the light availability to grass and the cycling of nutrients. After 140 days of evaluation, T1 gained 0.491 g/animal/d and T2 0.245 g/animal/d and there was no effect of animals on the tree growth, but the fertility of soils was lower in the SPS than in the area without trees (**Table 6**). These results indicate that the change in soil fertility was not too drastic to affect the tree growth in the short term, but long-term management strategies should consider reducing the tree density to promote nutrient cycling in the system.

Picture 3. Beef cattle in a SPS of *Leucaena leuocephala* and grass. Picture from John Jairo Lopera, El Porvenir farm, Cesar, Colombia

	Texture and pH	N, gkg^{-1}	Organic matter, gkg^{-1}	P, ppm	Ca, cmol(+)kg^{-1}	Mg, cmol(+)kg^{-1}	K, cmol(+)kg^{-1}
T1	F-A 5.16	2.0	42.0	35.1	2.83	0.56	0.32
T2	F-A 5.31	1.9	41.0	33.	6.52	1.77	0.43
T3	F-A 5.74	4.2	103.0	35.	1.08	0.26	0.48
T4	F-A 5.68	4.1	102.0	49.0	4.35	1.43	0.64

T1= Plot with trees of 5 m without animals; T2= Plot with trees of 5 m with animals; T3= Plot with trees of 10 m without animals; T4= Plot with trees of 10 m with animals

Table 6. Effect of tree height and presence of animals in silvopastoral systems on the soil fertility

9. Impact of the silvopastoral systems on the dairy cattle production

The area to be covered by SPS on farms varies between 15-100% and in all cases, the stocking rate and milk productivity is increased by the transformation of the pasturelands without trees. However, farms vary a lot according to the intensity of trees and shrubs that are included in the SPS, which determines the different relationships between components and the cycling of nutrients, with increases that fluctuate between 87.5 and 166.6 % for stocking rate, and 20-35% for milk production (**Murgueitio et al. 2006**). The increase of the land use with high density SPS of *C.pleactostachyus*, *L.leucocephala* and *P.juliflora* in the Hatico Natural Reserve, Colombia, has led to an increase the stocking rate 31% and the milk production 95% during the last 10 years (**Table 7**) (**Molina et al. 2009**). This SPS also offers higher quality of milk fat related to a higher composition of conjugated linoleic acid (CLA), which has been reported as beneficial for human health (**Mahecha et al. 2008**). Improvement in milk production have also found with *Tithonia diversifolia* used as protein bank for cutting and carrying its forage for animals. **Mahecha et al. (2007b)** evaluated the quantity and quality of milk of F1 cows Holstein x Zebu supplemented with forage of *T.diversifolia* as a partial replacement of concentrate food. The authors did not find significant differences in milk yield during the rainy and dry season; cows fed 100% concentrate food produced 12.5 and 11.71 L /day (rainy and dry season, respectively) compared to 12.4 and 12.16 L /day (rainy and dry season, respectively) of cows fed a concentrate consisting of 35% *T.diversifolia* forage. Likewise, the milk protein level was increased from 3.51% to 3.82% (100% concentrate and 35% replacement, respectively). New experiments are being carrying out with *T.diversifolia* in high density SPS, which allows grazing animals direct access to this potential forage on acid soils of Caqueta, Colombia with low phosphorus and high aluminum saturation.

Picture 4. Lucerna dairy cows in a high density SSP. Hatico Natural Reserve, Colombia. Picture from Liliana Mahecha

Variables	Year											
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total area ha	89	89	89	73	51	63	49.6	49.6	49.6	52.8	56	61
Area without Leucaena ha	75.4	68.2	61.8	29.8	0	0	0	0	0	3.2	0	0
Area with Leucaena ha	13.6	20.8	27.2	43.2	51.0	62.2	48.6	49.6	49.6	49.6	56	61
Number of milking cows	299	286	259	266	230	304	259	244	252	260	246	248
Stocking rate cows/ha/year	3.35	3.21	2.91	3.74	4.5	4.82	5.22	5.04	5.08	4.92	4.4	4.1
Milk production L/ha/year	7 436	8 298	9 770	11 684	17 025	16 798	18 290	18 486	17 857	16 501	14 306	14 473

Source: Molina et al (2009)

Table 7. Effect of the increase of SPS on the land use on the stocking rate and milk production in the Hatico Natural Reserve, Colombia

In summary, this chapter showed that livestock production system can be environmentally friendly, efficient and productive when diversified plant communities are supported through the use of SPS. This system relies on optimizing relationships between components (soils-plants-animals) to obtain appropriate nutrient balances/recycling, high vegetal biomass production and the multiple benefits for grazing cattle mentioned above.

10. References

Amezquita M.C, Amezquita E, Casasola F, Ramirez B.L, Giraldo H, Gomez M.E, Llanderal T, Velazquez J, Ibrahim M.A. 2008. C stocks and sequestration,. En: Carbon sequestration in tropical grassland ecosystems. Edited by L. 't Mannetje, M.C. Amézquita, P. Buurman and M.A. Ibrahim.

Belsky AJ, Mwonga SM, Duxbury JM. 1993. Effects of widely spaced trees and livestock grazing on understory enviroments in tropical savannas. Agroforestry Systems, 24:1-20.

Beer C.A, Harvey M, Ibrahim M, Harmand E, Somarriba E and Jiménez F. 2003. XII world forestry congress. Quebec, Canada.

Chamorro D and Obando A.M. 2009. El component arbóreo como dinamizador del sistema de producción de leche en el trópico alto colombiano. Experiencias de Corpoica. Tibaitatá. In: Murgueitio, E., Cuartas, C., Naranjo, J.F. (Eds.), Ganadería del futuro: Investigación para el desarrollo. Fundación CIPAV. Cali, Colombia, pp. 351-397.

Calle Z and Murgueitio E. 2011. El guasimo: uno de los árboles más adaptables a los sistemas silvopastoriles del trópico americano. Carta Fedegan 121.

Calle Z, Murgueitio E, Botero L.M. 2011. El Totumo, árbol de la Américas para la ganadería moderna. Carta Fedegán 122:64-73.

Calle Z and Murgueitio E. 2010. Botón de oro. Arbusto de gran utilidad para sistemas ganaderos de tierra caliente y de montaña. Carta Fedegán 108:54-59.

Crespo G, Castillo E, Rodriguez I. 1998. Estudio del reciclaje de N, P y K en dos sistemas de producción de vacunos de carne en pastoreo. En Memorias III taller Internacional silvopastoril realizado del 23-27 de noviembre 1998. Cuba. 234-236.

Fassbender H. 1993. Modelos edafológicos de sistemas agroforestales; 20. Edición. CATIE. Turrialba. Costa Rica. 490 p.

Giraldo C, Escobar F, Chara J, Calle Z. 2011. The adoption of silvopastoral systems promotes the recovery of ecological processes regulated by dung beetles in the Colombian Andes. Insect Conservation and Diversity 4: 115–122.

Gómez JE, Velásquez JE. 1999. Proceso integral de recuperación y manejo de praderas, condición fundamental para el desarrollo ganadero en Caquetá.

Boletín Técnico Corpoica-Pronatta. 42 p.

Ibrahim M. 2001. Potencialidades de los sistemas silvopastoriles para la generación de servicios ambientales. Conferencia electronica en potencialidades de los sistemas Silvopastoriles para la generación de servicios ambientales. FAO.

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Lindemann W.C and Glover C.R. 2008. Nitrogen Fixation by Legumes. Guide A-129. College of Agriculture and Home economics.

Lucero C. 2009. Evaluación agronómica de G. ulmifolia a dos densidades de siembra en sistemas silvopastoriles con B. arrecta. Consulta: 30 de mayo, 2010 de http://www.agronet.gov.co

Mahecha L, L.; Durán C., C.V.; Rosales M. 2000. Análisis de la relación planta-animal desde el punto de vista nutrición en un sistema silvopastoril de Cynodon plectostachyus, Leucaena leucocephala y Prosopis juliflora en el Valle del Cauca. Acta Agron , 50(1 y 2): 59-70.

Mahecha, L. 2002. El silvopastoreo: una alternativa de producción que disminuye el impacto ambiental de la ganadería bovina. Rev Col Cienc Pec Vol. 15(2):226-231.

Mahecha L, Gallego L, Pelaez F. 2002. Situación actual de la ganadería de carne en Colombia y alternativas para impulsar su competitividad y sostenibilidad.. Rev Col Cienc Pec Vol. 15: 2, 2002.

Mahecha, L. 2003. Importancia de los sistemas silvopastoriles y principales limitantes para su implementación en la ganadería colombiana. Rev Col Cienc Pec Vol. 16(1): 11-18.

Mahecha L and Rosales M 2005 Valor nutricional del follaje de Botón de Oro Tithonia diversifolia (Hemsl.) Gray, en la producción animal en el trópico. Livestock Research for Rural Development. Volume 17, Artículo 100. http://www.cipav.org.co/lrrd/lrrd17/9/mahe17100.htm

Mahecha L, Monsalve M A y Arroyave J F 2007a. Evaluation of grass availability and growth of Zebu steers in a silvo-pastoral system based on Eucalyptus tereticornis and Panicum maximum in the San Sebastian reforestation program in Magdalena Department of Colombia. Livestock Research for Rural Development. Volume 19, Article #94. Retrieved March 20, 2011, from http://www.lrrd.org/lrrd19/7/mahe19094.htm

Mahecha L, Escobar J.P, Suárez J.F y Restrepo L.F. 2007b. Tithonia diversifolia (hemsl.) Gray (Botón de oro) as forage supplement of Holstein x Zebu cows. Livestock Research for Rural Development. Volume 19, Article #16. Retrieved October 17, 2009, from http://www.lrrd.org/lrrd19/2/mahe19016.htm

Mahecha L, Angulo J, Salazar B, Cerón M, Gallo J, Molina C.H, Molina E.J, Suárez J.F, Lopera J.J and Olivera M. 2008. Supplementation with bypass fat in silvopastoral systems diminishes the ratio of milk saturated/unsaturated fatty acids. Tropical Animal Health and Production 40(3): 209-216.

Mahecha L, Murgueitio MM, Angulo J, Olivera M, Zapata A, Cuartas C.A, Naranjo J.F, Murgueitio E. 2011. Desempeño animal y características de la canal de dos grupos raciales de bovinos doble propósito pastoreando en Sistemas Silvopastoriles Intensivos. Rev Colomb Cienc Pecu 24 (4), dic 2011.

Manriquez-Mendoza L, Lopez-Ortiz S, Perez-Hernandez P, Ortega-Jimenez E, Lopez-Tecpoyotl Z, Villaruel-Fuentes M. 2011. Agronomic and forage characterization of *Guazuma ulmifolia* Lam. Tropical and subtropical ecosystems 14: 453-463.

Molina C.H, Molina C.H, Molina E.J. 2005. La Reserva Natural El Haico: Ganaderia competitiva y sostenible basada en el silvopastoreo intensivo . Carta Fedegán 95: 74-76.

Molina C.H, Molina-Durán C.H, Molina E.J, Molina, J.P. 2009. Carne, leche y mejor ambiente en el sistema silvopastoril con Leucaena leucocephala. In: Murgueitio, E., Cuartas, C., Naranjo, J.F. (Eds.), Ganadería del futuro: Investigación para el desarrollo. Fundación CIPAV. Cali, Colombia, pp. 41–65.

Murgueitio E, Calle Z, Uribe F, Calle A, Solorio B. 2011. Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. Forest Ecology and Management 261:1654–1663.

Murgueitio E, Cuellar P, Ibrahim M, Gobbi J, Cuartas C.A, Naranjo J.F, Zapata A, Mejía C.E, Zuluaga A.F, Cassasola F. 2006. Adopción de sistemas agroforestales pecuarios. Adoption of agroforestry systems for animal production.Pastos y Forrajes 29 (4): 365-379.

Murgueitio, E., Ibrahim, M., 2001. Agroforestería pecuaria para la reconversión de la ganadería en Latinoamérica. Livest. Res. Rural Dev. 13 (3), http://www.lrrd.org/lrrd13/3/murg133.htm.

Nardone A.B, Ronchi, et al. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science 130 (1-3): 57-69.

Pardo-Locarno, L. C. 2009. Macroinvertebrados edafícolas en agroecosistemas del municipio de El Cerrito (Valle), con énfasis en la comunidad de escarabajos Melolonthidae (Coleoptera: Scarabaeoidea). Doctorado, Universidad del Valle.

Pasalodos-Tato M, Pukkala T, Rigueiro-Rodríguez A, Fernández-Núñez E and Mosquera-Losada M.R. 2009. Optimal Management of Pinus radiata Silvopastoral Systems Established on Abandoned Agricultural Land in Galicia
(North-Western Spain). Silva Fennica 43(5): 831-845.

Ramirez H. Evaluación agronómica de dos sistemas silvopastoriles integrados por pasto estrella, Leucaena y Algarrobo forrajero. Tesis de Grado Universidad Nacional Bogotá. 1998.

Rios N, Jimenez F, Ibrahim M, Andrade H, Sancho F. 2006. Parámetros hidrológicos y de cobertura vegetal en sistemas de producción ganadera en la zona de recarga de la cuenca del río jabonal , Costa Rica.

Rodríguez FRA. 1985. Producción de biomasa de Poró gigante (*E. Poeppigiana*) y king grass (*P. purpureum * P. thypoides*) intercalados en función de la densidad de siembra y la biomasa de poda del Poró. CATIE. Tesis Mg. Sc.

Sadeghian S, Rivera JM, Gómez ME. 1998. Impacto de la ganadería sobre las características físicas, químicas y biológicas de suelos en los andes de Colombia. En: Memorias de la conferencia electrónica sobre agroforestería para la producción animal en América Latina, realizada de abril a septiembre de 1998. CIPAVFAO. p 123-141.

Sánchez M. 1998. Sistemas agroforestales para intensificar de manera sostenible la producción animal en América Latina Tropical. En: Memorias de la conferencia electrónica sobre agroforestería para la producción animal en América Latina, realizada de abril a septiembre de 1998. CIPAV-FAO. 1-13.

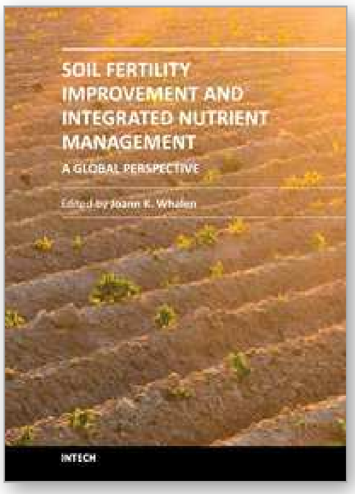
Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, De Haan C. 2006. Livestock's Long Shadow, Environmental Issues and Options. LEAD-FAO. Rome.

Vallejo V, Roldan F, Richard D. 2010. Soil enzymatic activities and microbial biomass in an integrated agroforestry chronosequence compared to monoculture and a native forest of Colombia. In: Colombia Biology And Fertility Of Soils ISSN: 0178-2762 ed: Springer v.1 fasc.1 p.1 - 1 ,2010.

Velasco J, Camargo J, Andrade H, Ibrahim M.1999. Mejoramiento del suelo por *Acacia mangium* en un sistema silvopastoril con *B. humidicola*. En: Memorias

VI Seminario Internacional sobre sistemas agropecuarios sostenibles. 28-30 de Octubre 1999. Realizado por la Fundación CIPAV y LA FAO. Cali, Colombia.

Vásquez R, Pulido J, Abuabara Y, Martínez R, Abadía B, Arreaza L.C, Silva J, Sánchez L.E, Ballesteros H, Muñoz C, Rivero T, Nivia A, Barrera G. 2005. Patrones tecnológicos y calidad de la carne bovina en el Caribe colombiano. Corpoica. Plan de modernización de la Ganadería. Ed. Camilo Baqu



Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective

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Soil Fertility Improvement and Integrated Nutrient Management: A Global Perspective presents 15 invited chapters written by leading soil fertility experts. The book is organized around three themes. The first theme is Soil Mapping and Soil Fertility Testing, describing spatial heterogeneity in soil nutrients within natural and managed ecosystems, as well as up-to-date soil testing methods and information on how soil fertility indicators respond to agricultural practices. The second theme, Organic and Inorganic Amendments for Soil Fertility Improvement, describes fertilizing materials that provide important amounts of essential nutrients for plants.The third theme, Integrated Nutrient Management Planning: Case Studies From Central Europe, South America, and Africa, highlights the principles of integrated nutrient management. Additionally, it gives case studies explaining how this approach has been implemented successfully across large geographic regions, and at local scales, to improve the productivity of staple crops and forages.